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# A logical investigation of false-belief tasks

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## Introduction

In this note we describe an interdisciplinary research project that uses logic to investigate psychological reasoning tests called false-belief tasks. Logical proofs, built according to the rules of a precisely defined proof-system, have been used for over a century to represent—describe the structure of—mathematical reasoning; nowadays there is increasing interest in using them to analyze reasoning in everyday human practice. The goal of our project is to analyze and give logical formalizations of false-belief tasks using a range of modal proof-systems, and moreover, to use such logical analyses as a basis for empirical studies of how children with Autism Spectrum Disorder (ASD) reason in false-belief tasks.

A well known example of a false-belief task is the Sally-Anne test:

*A child is shown a scene with two doll protagonists, Sally and Anne, having respectively a basket and a box. Sally first places a marble into her basket. Then Sally leaves the scene, and in her absence, Anne moves the marble and puts it in her box. Then Sally returns, and the child is asked: “Where will Sally look for her marble?”*

Children above the age of four typically give a correct response to this task: they say that Sally will look in the basket, which is where Sally (falsely) believes the marble to be. Younger children, on the other hand, say that Sally will look in the box: this is indeed where the marble is, but this information is not available to Sally and hence the response is incorrect. For children with ASD, the shift to correct responses usually occurs at a later age.

Passing the Sally-Anne test involves taking the perspective of another agent, namely Sally, and reasoning about what she believes. So to speak, you have to put yourself in Sally’s shoes to get the answer right. Since the ability to take a different perspective is a precondition for figuring out the correct answer to the Sally-Anne (and other) false-belief tasks, the fact that children with ASD have a higher cutoff age is taken by some researchers to support the hypothesis that ASD may be due to a limited or delayed Theory of Mind (ToM), the ability to ascribe mental states, for example beliefs, to other people. The book (Baron-Cohen, 1995) is the classic statement of this view.

The Sally-Anne task given above, and another false-belief task called the Smarties task, were formalized in (Braüner, 2013, 2014) using a natural deduction proof-system for hybrid modal logic taken from the book (Braüner, 2011), and tracing back to (Seligman, 1997). The later paper (Braüner,

2015) considers what goes wrong when incorrect responses are given to false-belief tasks.

Hybrid modal logic is an appropriate tool to analyse the reasoning in these false-belief tasks since it can explicitly represent perspectives (perspectives can be named), and moreover, the natural deduction system we use can explicitly represent shifts between different perspectives (it is dealt with by a specific proof-rule).

## Second-order false-belief tasks

The papers mentioned above dealt with *first-order* false-belief tasks; they are psychological tests where the experimental subject must ascribe a false-belief to another person. Handling first-order false-beliefs correctly is viewed as a milestone in the acquisition of ToM, one typically reached at the age of four. The mastery of *second-order* false-beliefs is a later milestone in ToM acquisition, one typically reached at age six or seven. In a second-order false-belief task, the subject must keep track of a second person’s belief about a third person’s belief—it thus requires understanding of the recursive character of mental states. Second-order false-belief reasoning has been found to correlate with a number of other abilities necessary for complex social interaction: idiom understanding, irony and sarcasm understanding and understanding of social emotions such as embarrassment; see the book (Miller, 2012) for an overview. The recent paper (Grueneisen, Wyman, & Tomasello, 2015) also shows correlation with peer coordination.

Much less is known about second-order false-belief understanding than its first-order cousin, in particular when it comes to children with ASD; see (Miller, 2012). We have published formalizations of second-order false-belief tasks in the papers (Braüner, Blackburn, & Polyanskaya, 2016a, 2016b). The latter paper includes a logical comparison of the four well known second-order false-belief tasks that can be found in the literature, showing that they are logically distinct and can be classified across two dimensions of variation.

These formalizations also highlights the importance of recursion: they show that second-order reasoning can be viewed as the recursive embedding of first-order reasoning about different agents—but as recursive logics of belief are more complex than those required to analyze first-order false-belief tasks, processing issues are also relevant and should be experimentally investigated.

## Empirical study: Second-order social reasoning in children with ASD

Our empirical line of work centers around the notion of recursion. We have carried out a correlation and training study of second-order social reasoning competency in

high-functioning children with ASD, the hypothesis being that training in linguistic recursion (in particular, handling of sentential complements) will improve their social cognition skills, as measured by second-order false-belief tasks. More precisely, we measure the second-order reasoning capacity using a composite score involving all four reasoning patterns singled out by our logical analysis; see (Braüner et al., 2016b). Our study involves 62 Danish-speaking children with ASD. Results are in press; see (Polyanskaya, Braüner, & Blackburn, 2018). See also (Polyanskaya, Blackburn, & Braüner, 2017) for a more detailed discussion of the background ideas.

## Comparison to other work

There have been few previous applications of logical methods to false-belief tasks. The pioneering work is due to Stenning and Van Lambalgen, who analyse the Sally-Anne and other first-order false-belief tasks in terms of non-monotonic closed world reasoning as used in logic programming; see their book (Stenning & van Lambalgen, 2008). The paper (Arkoudas & Bringsjord, 2008) describe how reasoning in the first-order Sally-Anne test have been implemented in an interactive theorem prover using axioms and proof-rules formulated in a many-sorted first-order modal logic. Unlike our hybrid-logical analyses, the proof-rules employed in (Stenning & van Lambalgen, 2008) and (Arkoudas & Bringsjord, 2008) do not explicitly formalize the perspective shift required to pass the Sally-Anne test.

Applications of logical models to second-order false-belief tasks are even rarer: a clear example is the use of Dynamic Epistemic Logic in (Bolander, 2014), its main feature being that reasoning is modeled with Kripke structures characterizing the uncertainty of agents. This line of work models the reasoning from a global perspective, that is, from the perspective of the modeler—see Section 5 of the paper (Verbrugge, 2009) for a general discussion of the problems with epistemic logic as a model for human social cognition. It is also relevant to mention the use of game theory in (Szymanik, Meijering, & Verbrugge, 2013) to investigate performance in higher-order social reasoning.

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